Vertical cavity testing at INFN

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PIP-II Technical Workshop: CAVITY PROCESSING AND TESTING

02/12/20

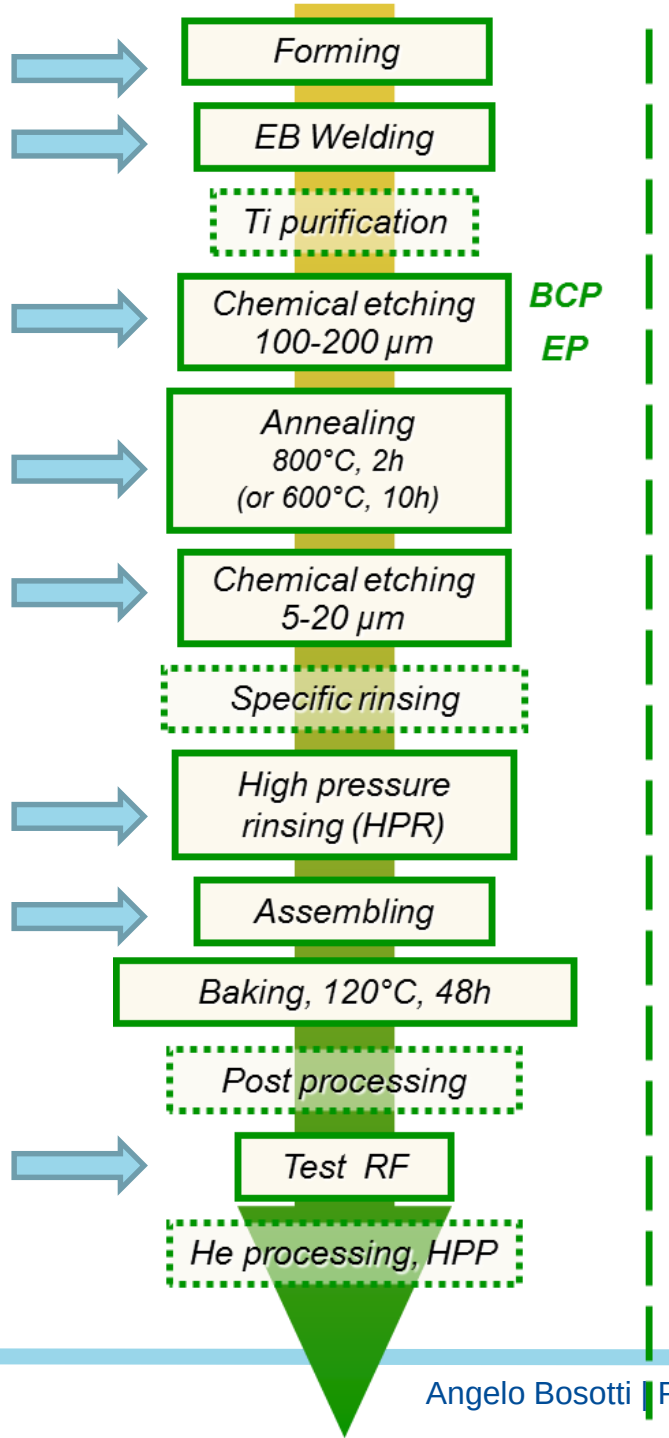
A Partnership of:

US/DOE
India/DAE
Italy/INFN
UK/UKRI-STFC
France/CEA, CNRS/IN2P3
Poland/WUST

Fabrication activities at LASA – INFN Milano

- INFN LASA has a long experience on cavity design and, in collaboration with industry, in fabrication of cavities
  - Copper cavities for **CS** (Superconducting Cyclotron) at **LNF**
  - Collaboration with **CERN** for Nb sputtering of **352.2 MHz LEP** copper cavities
  - Construction and test of four cell SC Niobium prototype cavity for **ARES/LISA** at 500 MHz (~ 1990)
  - Collaboration with **DESY** for the first **TTF** cavities
  - Collaboration with **LANL** (Advanced Accelerator Applications, **350 MHz**) and **FNAL** (HINS, **325 MHz**) for the construction of SC Spoke cavities
  - We have significantly contributed to the design of the **SNS cavities at 805 MHz**
  - **TRASCO cavities** were designed at LASA and fabricated at **704.4 MHz**
  - LASA was deeply involved in the mass production of the **800 cavities for XFEL at 1.3 GHz**
  - **20 3.9 GHz** cavities for the third harmonic module of **XFEL** were designed at LASA, fabricated and tested
  - **38 704.4 MHz** cavities for the Medium Beta Section of the **European Spallation Source**
  - **2 650 MHz** prototype cavities for the Low Beta Section of **PIP-II** in preparation for the 38 cavities in-kind contribution

Cavity construction and preparation overview (Borrowed from: Claire Antoine CAS Erice)

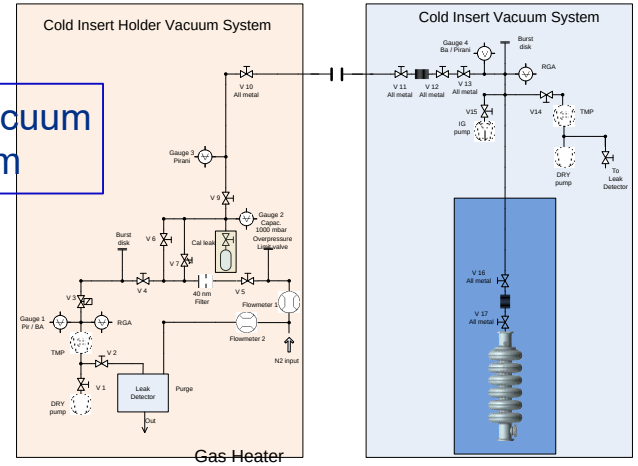


WHY	COMMENTS
Clean welding	Nb = getter material. If RRR/ 10 @ welding => Q_0/10
RRR enhancement	RRR 300-400 now commercially available
Remove contamination and damage layer	Limitation : BCP ~ 30MV/m; EP => >40 mV/m but lack of reproducibility
Get rid of hydrogen	Source of H: wet processes H segregates near surface in form of hydrides (= bad SC)
Remove diffusion layer (O, C, N)	Diffusion layer < ~1µm in bulk, a little higher at Grain Boundaries
e.g. remove S particles due to EP	Under evaluation HF, H_2O_2, ethanol, degreasing,…
Get rid of dust particles	Not always enough (recontamination during assembly)
Ancillaries : antennas, couplers , vacuum ports…	**In clean room, but recontamination still possible**
Decrease high field losses (Q-drop)	Unknown mechanism, first 10 nm of the surface in concern.
Get rid of "re-contamination" ?	Under evaluation: dry ice cleaning, plasma
Cavity's performance	First naked cavity in vertical cryostat, then dressed in horizontal cryostat/ accelerating facility
Decrease field emission	RF power with/ without He to destroy field emitters (dust particles) NB field emission : principal practical problem in accelerators

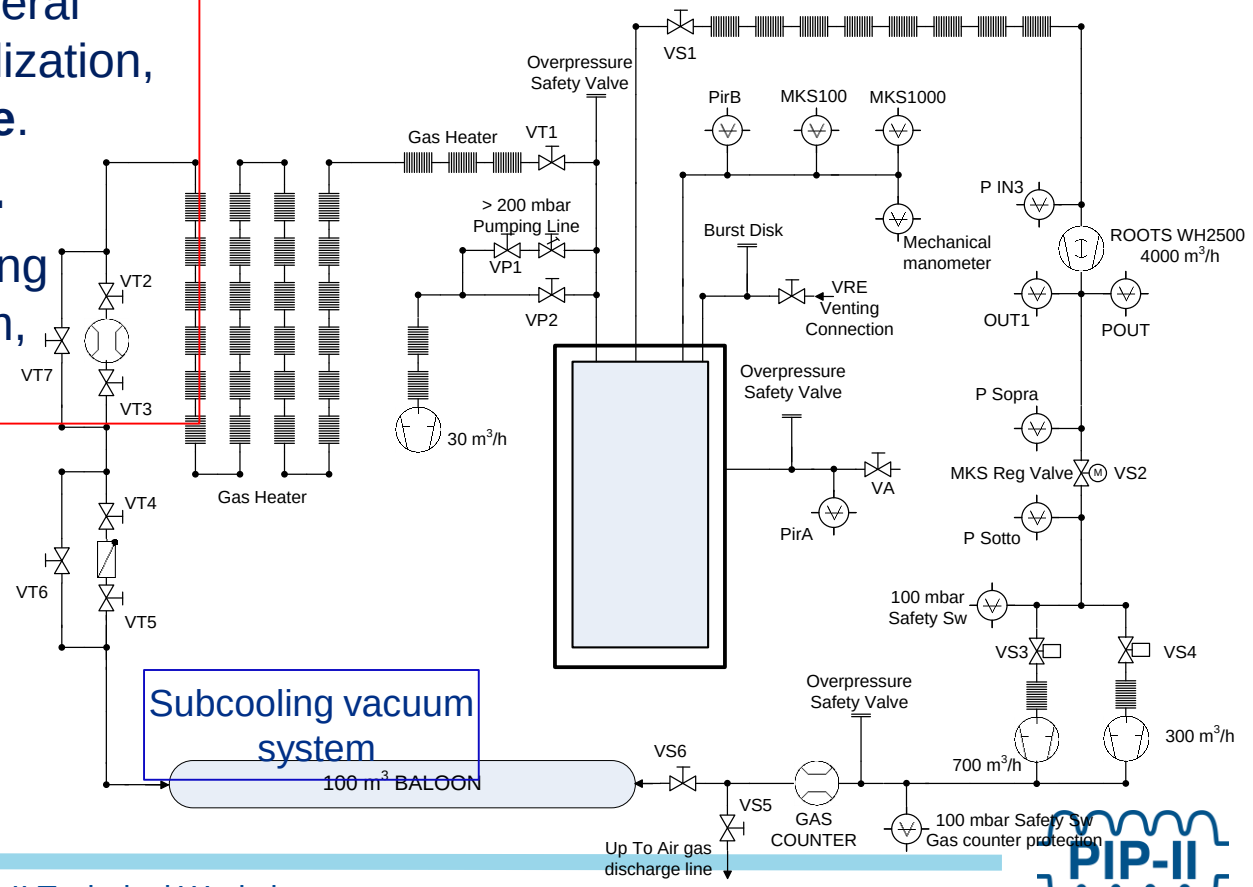
From: Claire Antoine CAS Erice

INFN - LASA ESS cold test infrastructure

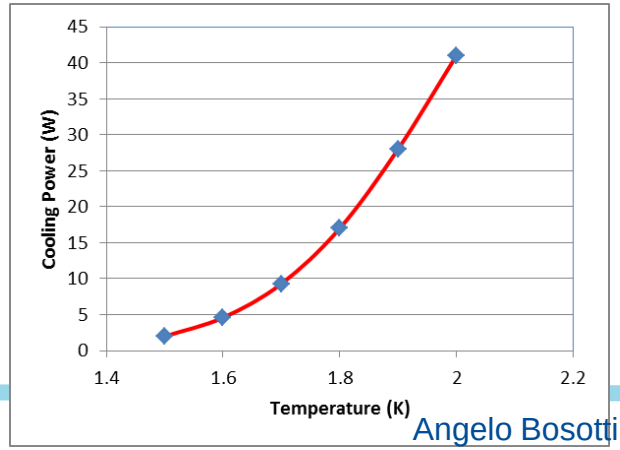
- **Cryostat**: ϕ 700 mm, 4.5 m length, **losses < 1 W@ 4 K**
- **Residual magnetic field**: < **8 mGauss**. Single μmetal external shield, second cryogenic shield (Cryoperm) in progress.
- **Subcooling system**: rotary vane pumps + roots pumps. Lowest temperature **1.5 K**. Cooling power: **~ 40 W @2 K**
- Dedicated cold vertical insert for ESS cavities with several diagnostics: **second sound** detectors for quench localization, **cryogenic photodiodes**, **fast thermometry, flux gate**.
- **X-ray counter** and **X-ray NaI spectrometer** available**.**
- **RF** power system, Qualified Slow Pumping Slow Venting (**SPSV**) system, Clean Room, Ultra Pure water System, HPR



"Cavity" vacuum system



Subcooling vacuum system



Cooling power vs. temperature

Summary of LASA VT facility characteristics

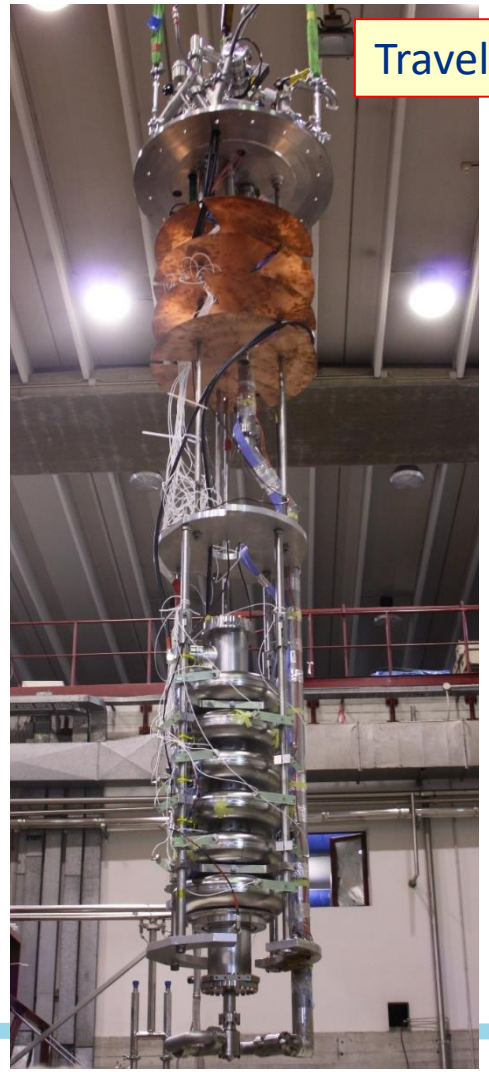
- Test capability for SC cavities with f > 500 MHz
- Control Electronics (PLL) and Power Amplifiers
  - 500 < f < 900 MHz, 500 W
  - 1.2 < f < 1.4 GHz, 500 W
  - 3.5 < f < 3.95 GHz, 200 W

  Cooling Power ~ 40 W @2 K
- Lowest temperature = 1.5 K
- Maximum accelerating gradient measured E_{acc} = 38 MV/m@2K

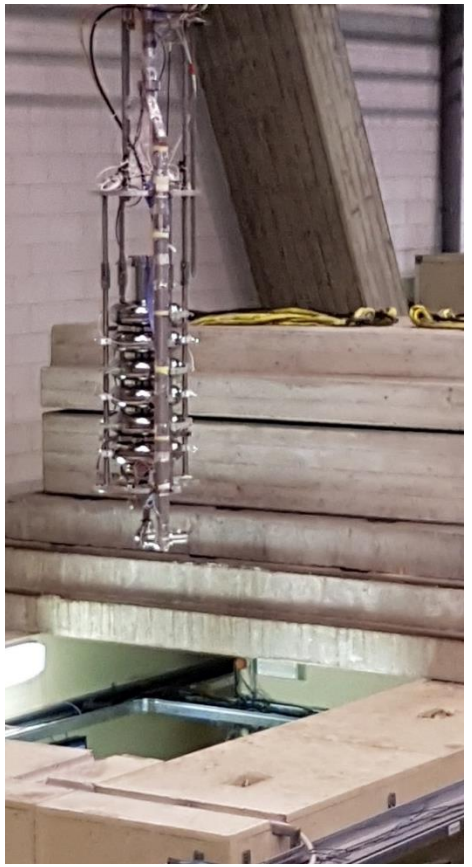
Cavity Installed On Insert

Connection to SPSV

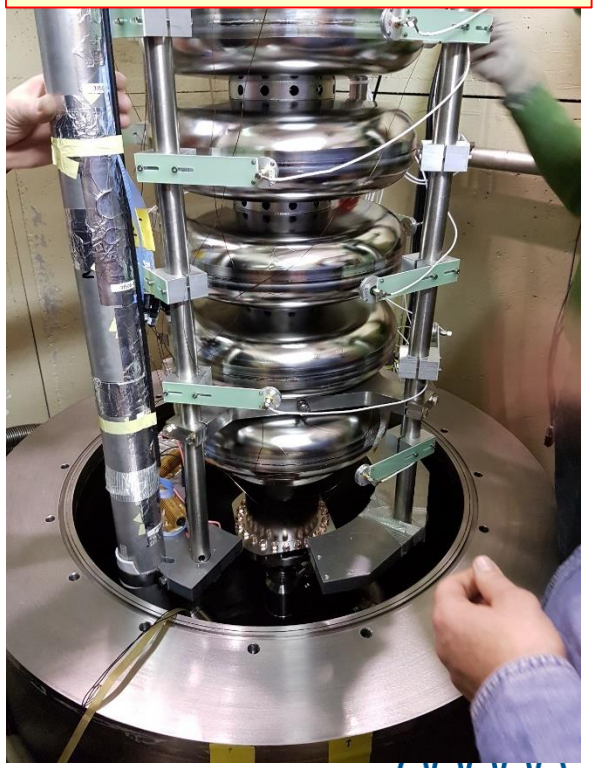
Cavity on Insert with sensors installed



Travelling on crane



Inserted in Vertical Cryostat



Helium transfer from Dewars to Vertical Test Cryostat

Temperature acquired with cryogenic Si Diode read by Lakeshore 224 Temperature Monitor

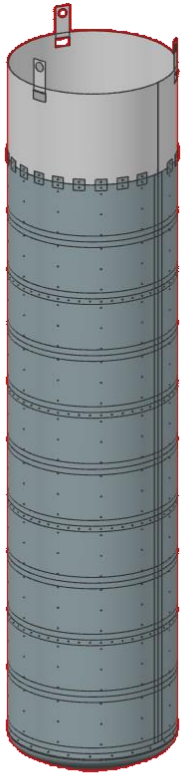
Transfer rates

- T > 30 K ≈ 2 K/m
- 30 K < T < 15 K ≈ 1 K/m
- T < 15 K ≈ 0.5 K/m

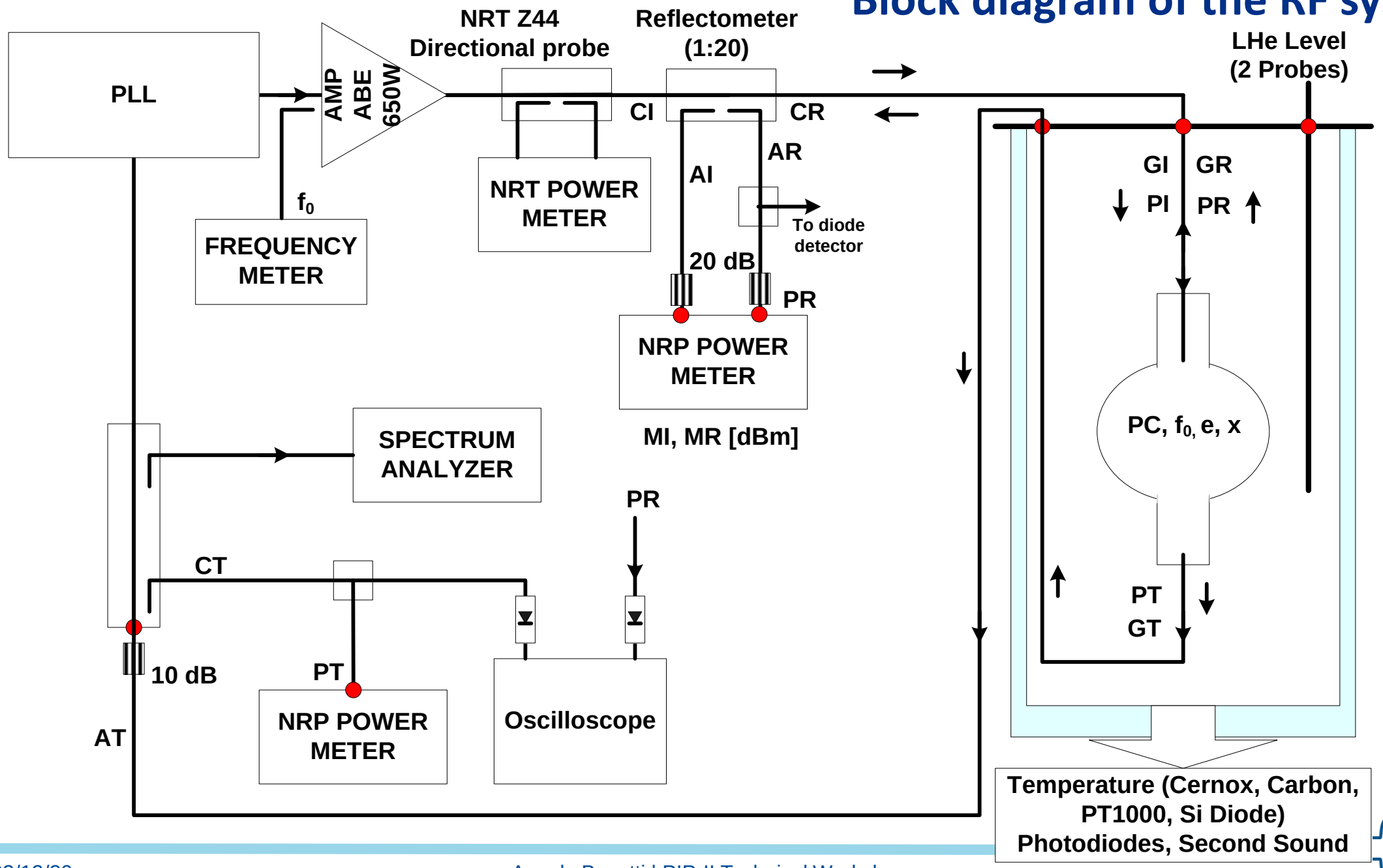
INFN-LASA infrastructure upgrades

INFN cold test **infrastructure at LASA is being upgraded**.

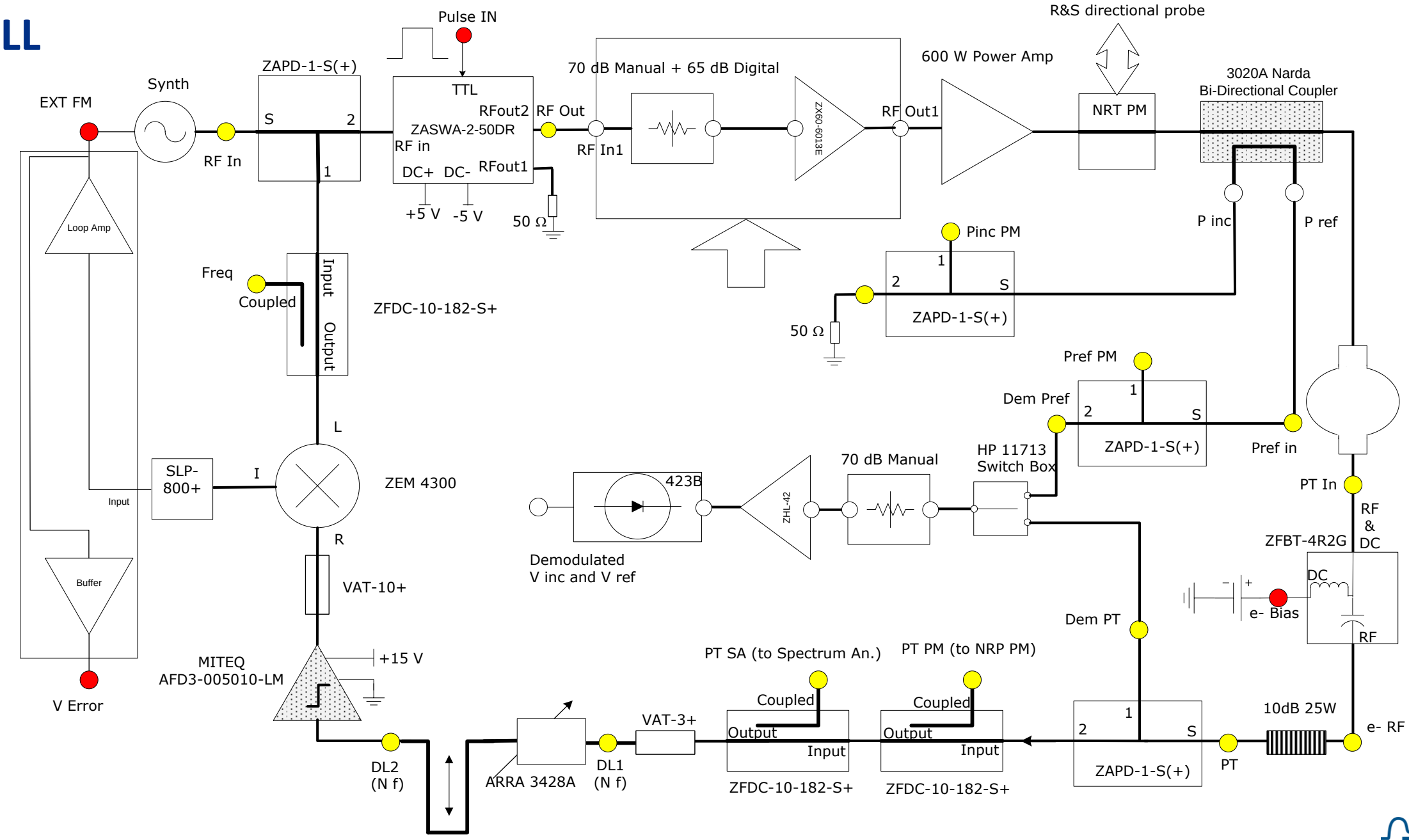
- Cylindrical **cryo-perm inner shield** ordered in order to halve the currently measured 8 mG average remnant field in the cavity equator region.
  - Test installation successfully done at LASA, heat-treatment done
- Development of active and dynamic local magnetic field cancelling through combined use of **Helmholtz's coils** and **flux-gate** sensors
  - Setting almost zero residual magnetic field when SC transition occurs
- Boost in cryogenic plant performances:
  - Higher cryogenic power, up to 70 W at 32 mbar
  - Refilling at 2.0 K option ordered, to extend cavity testing time by means of **counter-flow heat-exchanger** followed by a **Joule-Thomson expander.**
  - Faster cool-down rate, now at about 1-1.5 K/min



Block diagram of the RF system



PLL


Pulse IN
R&S directional probe
ZAPD-1-S(+)
Synth
TTL
70 dB Manual + 65 dB Digital
600 W Power Amp
3020A Narda
Bi-Directional Coupler
EXT FM
S
2
RFout2
RF Out
ZASWA-2-50DR
RF In1
RF Out1
NRT PM
RF In
1
RF in
DC+ DC-
RFout1
ZX60-6013E
+5 V
-5 V
50 Ω
P inc
P ref
Loop Amp
Pinc PM
Freq
Coupled
Input
Output
ZFDC-10-182-S+
50 Ω
ZAPD-1-S(+)
Pref PM
Dem Pref
L
SLP-
800+
I
ZEM 4300
HP 11713
Switch Box
70 dB Manual
423B
ZHL-42
Pref in
PT In
RF
&
DC
ZFBT-4R2G
Input
R
Demodulated
V inc and V ref
Buffer
VAT-10+
DC
e- Bias
RF
Dem PT
MITEQ
AFD3-005010-LM
+15 V
PT SA (to Spectrum An.)
PT PM (to NRP PM)
10dB 25W
V Error
VAT-3+
Coupled
Output
Input
e- RF
DL2
(N f)
ARRA 3428A
DL1
(N f)
PT
ZFDC-10-182-S+
ZFDC-10-182-S+
ZAPD-1-S(+)

Temperature Sensors

DT-670-SD-1.4L Silicon Diode

- Main Use to monitor cooldown to 4.2K
- Installed on the insert bottom plate
- T range 1K < T < 325 K
- From calibration curve 1<T<20K δT < 10 mK (4.2 K δT=2mK; 2K δT=0.07 mK!)

Cernox thin film resistance cryogenic temperature sensors

- Placed on cavity cells
- Used for Fast Thermometry

CCS Carbon Ceramic Sensors

- Installed on cavity cells for Fast Thermometry
- Installed along the insert for Standard Thermometry

PT1000

- Installed along the insert for Standard Thermometry

Vapor Pressure T < 4.2 K

- E.G.: T = 2K vp = 32 mbar
- Sensitivity < 0.1 mbar
- $\Delta T \approx 50$ mK@2K $\Delta p \approx 4.5$ mbar

Diode & Standard Thermomentry

- Lakeshore 224 Temperature Monitor

Fast Thermometry

- (Home-made) Custom Electronics
- 10 – 100 μA FET Current Generator
- Instrumentation Amplifier

Vertical Test Protocol

System Calibration (VNA + PM)

- ❑ A_I, A_R, A_T (S_{21}, RT)
- ❑ G_I, G_R, G_T (S_{11}, 4.2K and 2K)
- ❑ C_I, C_R, C_T (S_{21}, RT)
- ❑ Superfish: G, R/Q, L

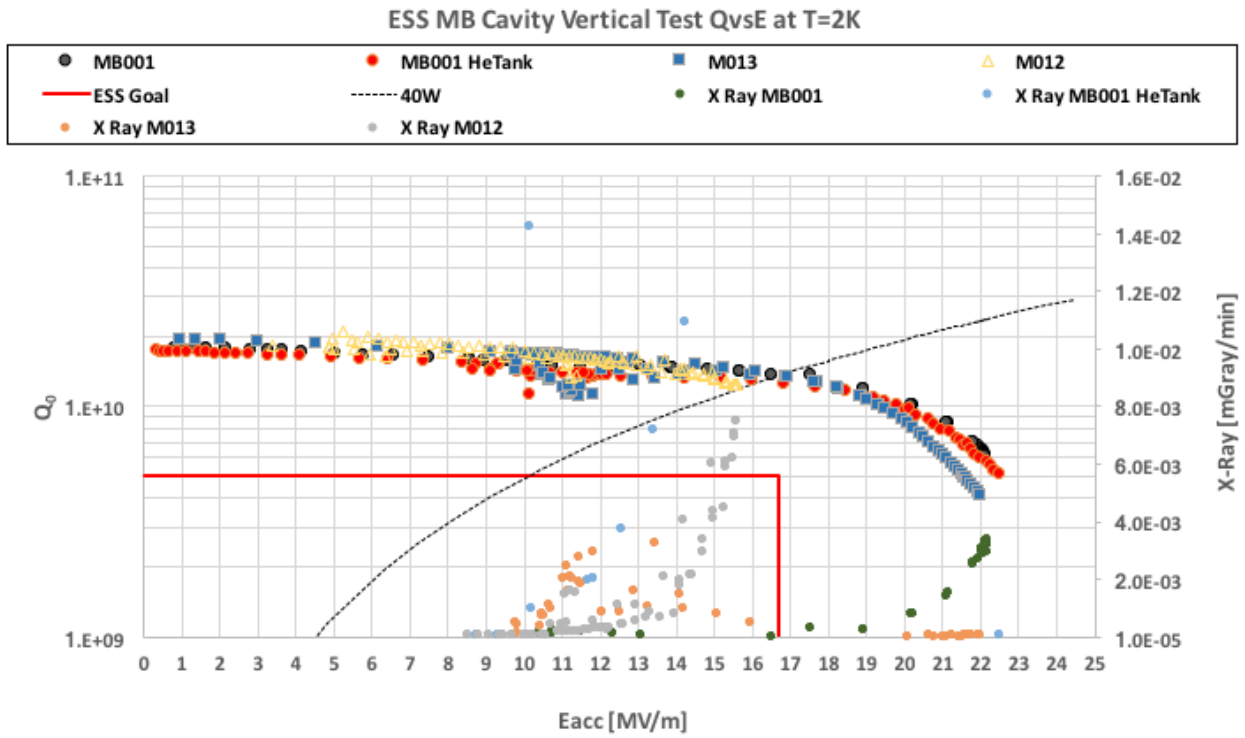
Subcooling

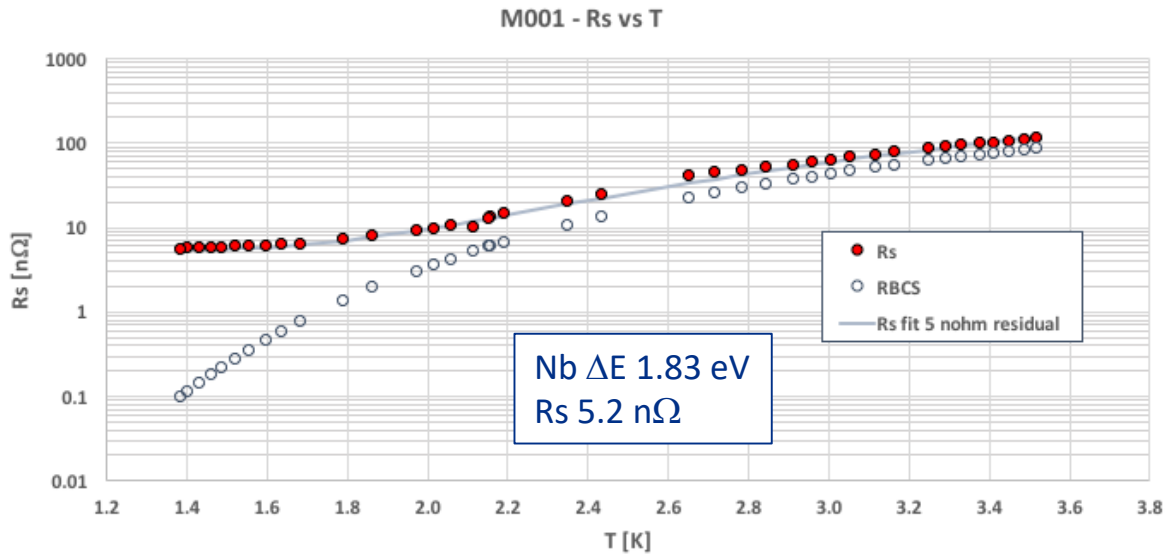
- ➢ **Acquired**
  - T, P_I, P_R, P_T, f_π, τ_{VT}
- ➢ **Computed**
  - P_C, Q_0, R_S

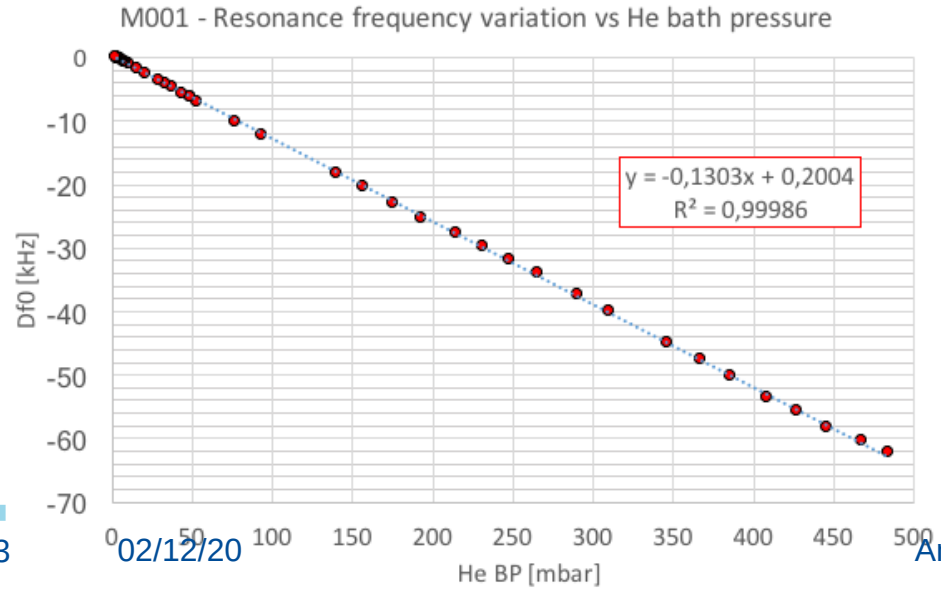
Cavity Qualification: Q_0 vs E_{acc}

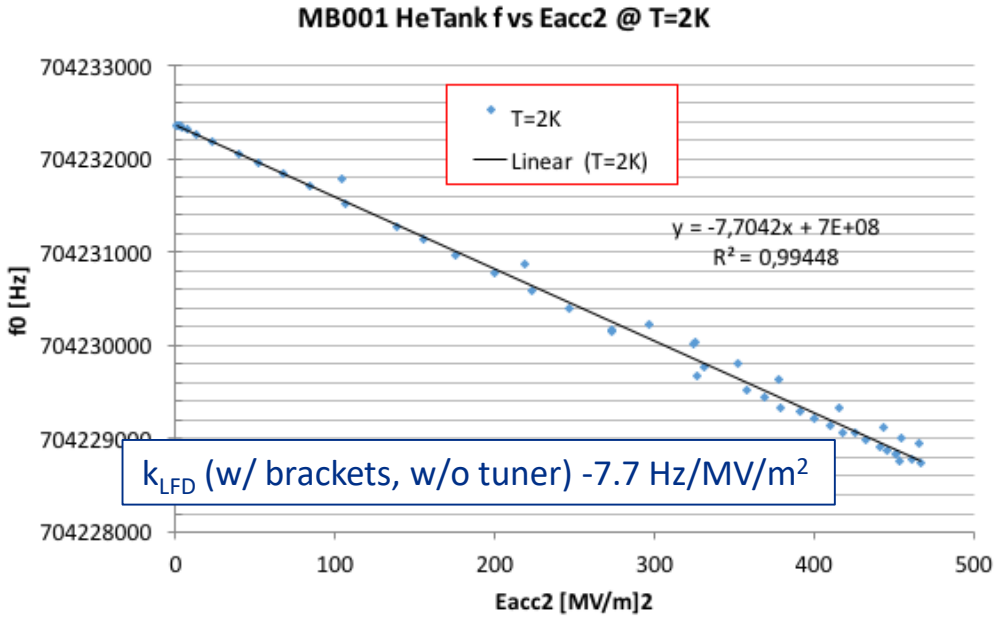
- ❑ **Calibration** @ 1 MV/m < E_{acc} < 2 MV/m
  - ❖ Acquired : P_I, P_R, P_T, f_π, τ_{VT}
  - ❖ Computed: P_C, Q_0, E_{acc}, $K_E = \frac{E_{acc}}{\sqrt{P_T}}$
- ❑ **Power Rise** → P_I raised via digital step attenuator
  - ❖ Acquired: P_I, P_R, P_T, f_π, τ_{VT}
  - ❖ Computed: P_C, Q_0, $E_{acc} = K_E\sqrt{P_T}$

Examples of RF Test Results

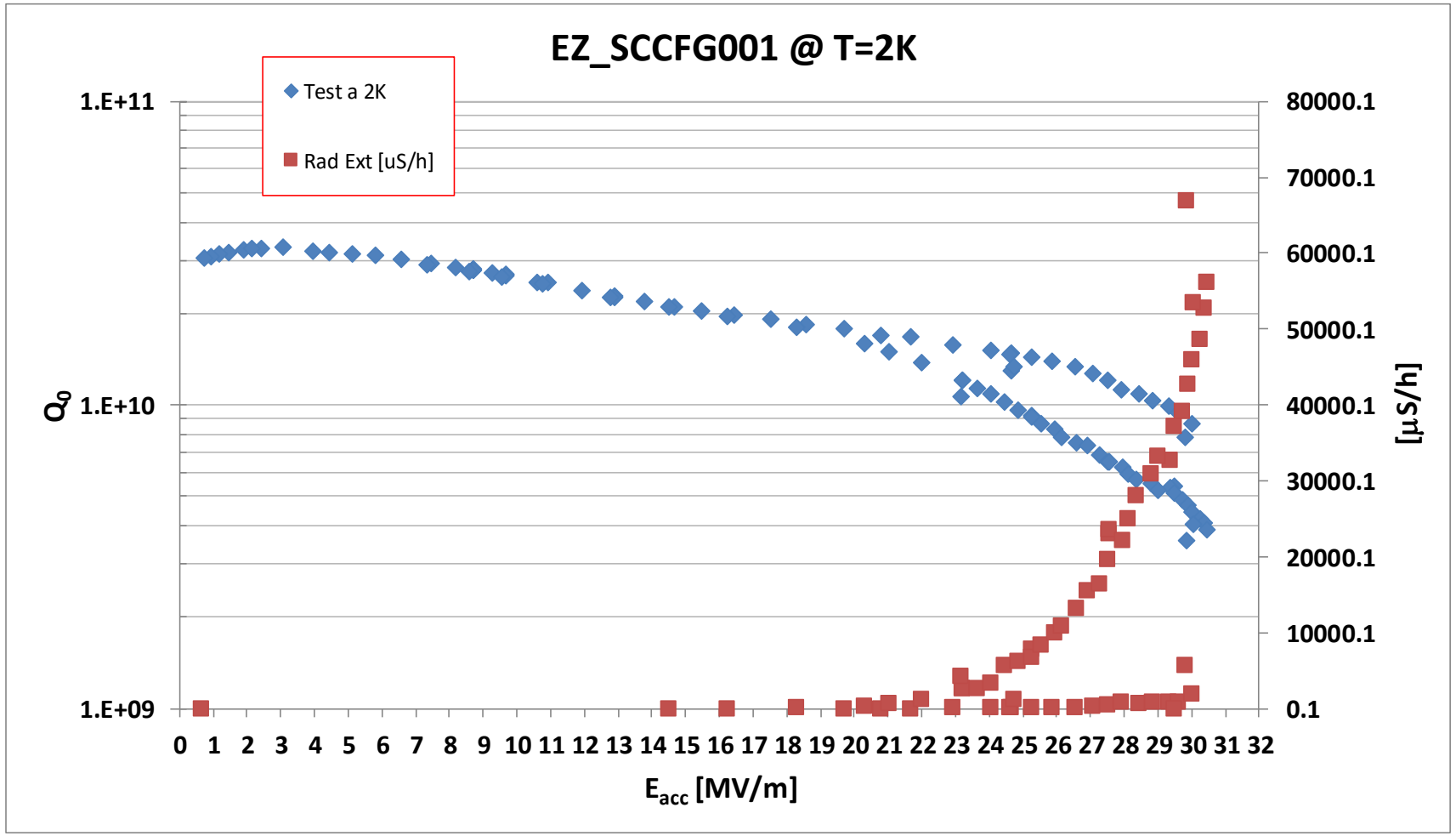






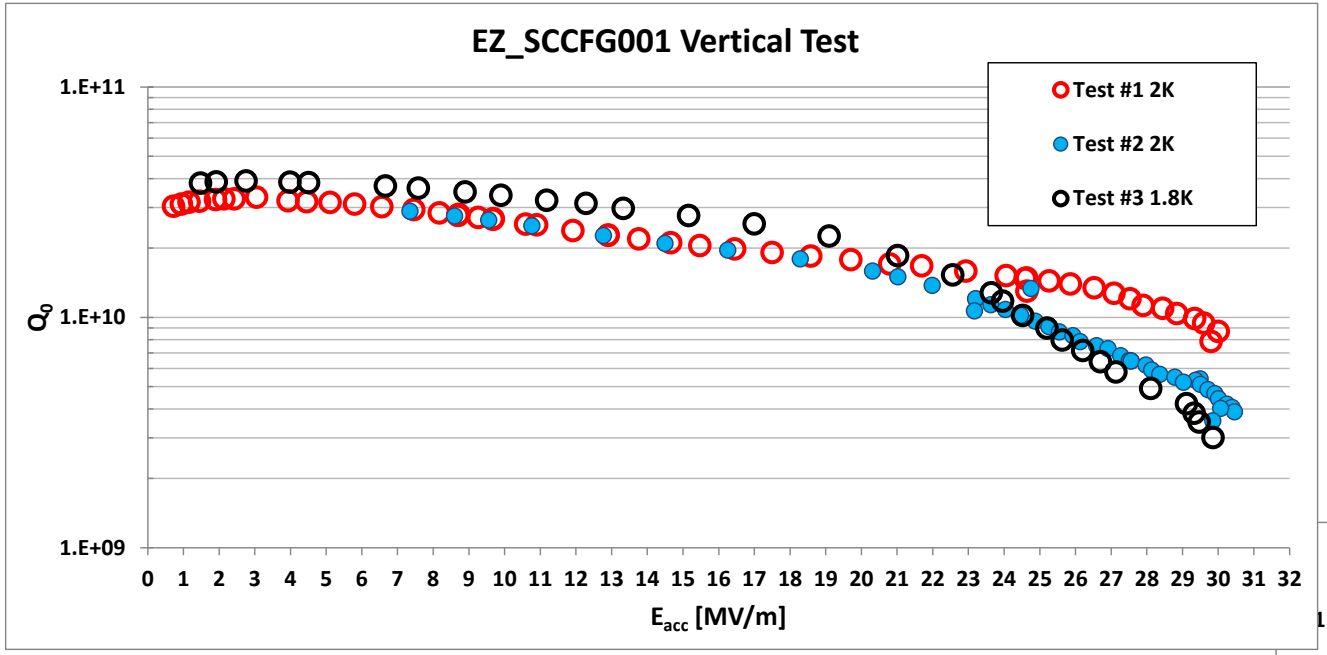


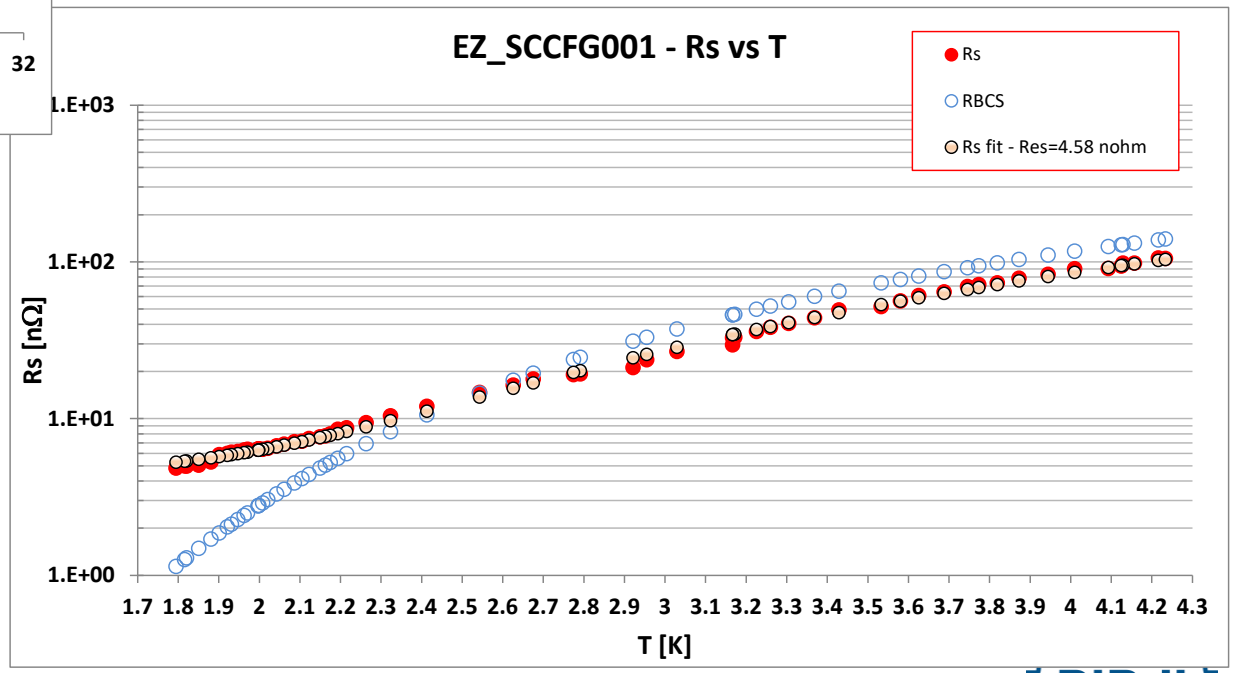
EZ_SCCFG001 Vertical Test @ T=2K Preliminary Data (12/01/2020) 1/2



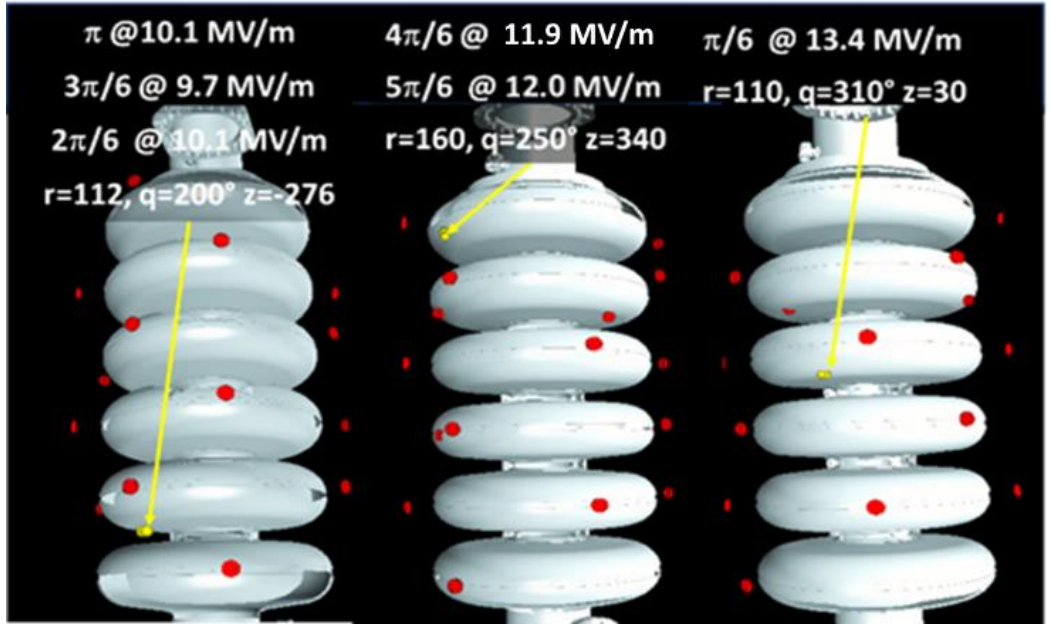
Q_0 Low Field	3.32×10^{10}
Max E_{acc} [MV/m]	30.5
Q_0@17 [MV/m]	2×10^{10}
P_{diss} [W]	4.7
Q_0@Max E_{acc}	4×10^{9}

EZ_SCCFG001 Vertical Test @ T=2K Preliminary Data (12/01/2020) 2/2

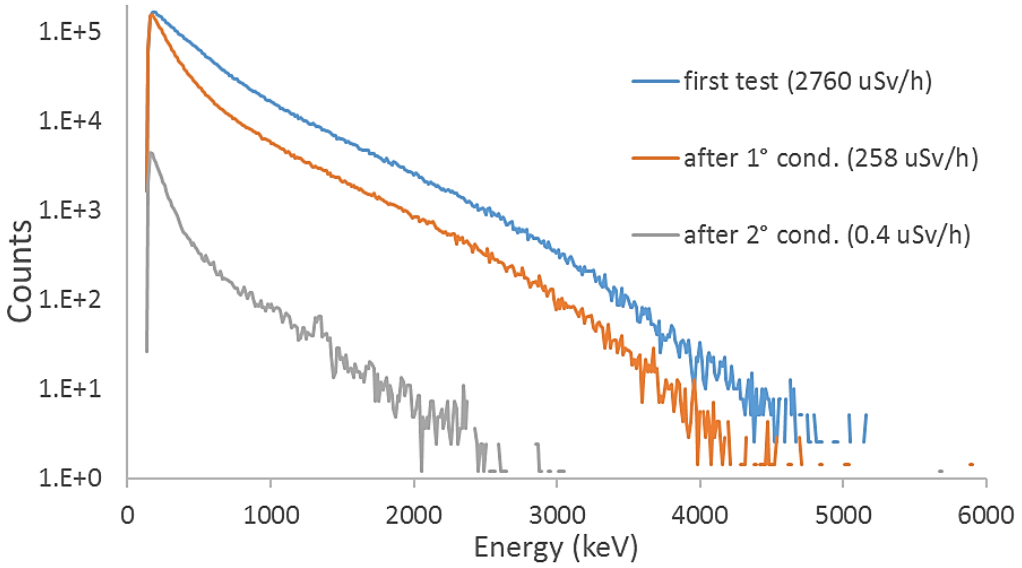




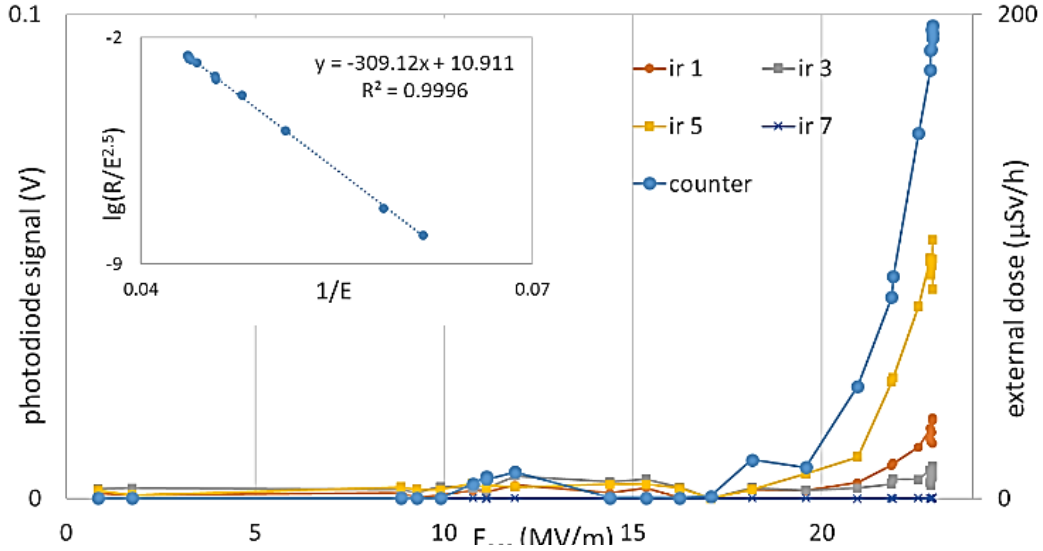
Examples of Diagnostic Results



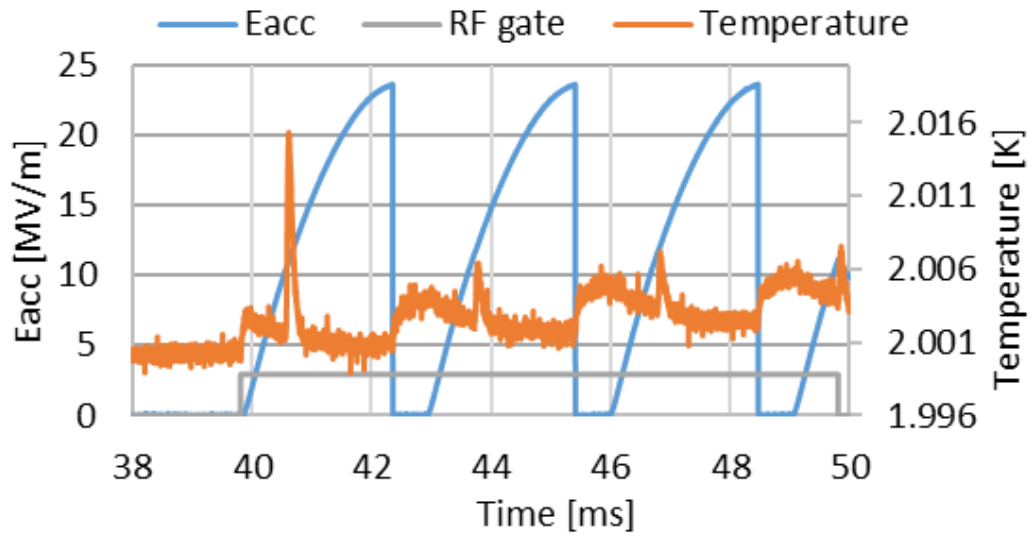
Second sound reconstruction of the 6 passband modes quench



Scintillation spectra at quench field before and after conditioning



Photodiode signals vs Eacc, labelled with corresponding cavity irises, and external radiation level



Cernox sensor during quench at 22 MV/m

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PIP-II